NONDESTRUCTIVE INVESTIGATION OF SOIL MOISTURE LEVEL USING OPTICAL SYSTEM

Mars Wai Hong Xuan

A thesis submitted in
fulfilment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

DECEMBER 2020

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged

Student : MARS
…………………………………
MARS WAI HONG XUAN

Date : 19 NOVEMBER 2020
…………………………………

Supervisor : …………………………………
DR. XAVIER NGU TOH IK

Co-supervisor : …………………………………
PROF. MADYA DR. AUDREY HUONG KAH CHING

To my beloved parents, supervisor and co-supervisor, thank you.

ACKNOWLEDGEMENT

Foremost, I would like to express my sincere gratitude to my supervisor, Dr. Xavier for the continuous support, encouragement and mentorship throughout the research. I could not have imagined having a better advisor and mentor for my study.

Besides my supervisor, I would like to thank my co-supervisor: Prof. Madya Dr. Audrey Huong for her insightful comments and encouragement.

Finally, I would like to express my heartfelt gratitude to my parents and siblings for their encouragement, moral support and supporting me spiritually throughout my life.

ABSTRACT

Soils are one of the essential resources consisting of unconsolidated mineral or organic material on the surface of the Earth; it plays an important role in the growth of land plants. Soil testing is an effort to assess the soil constituents and moisture level; this information is useful to evaluate soil fertility and plant survival. This research describes the use of an optical system combined with Artificial Neural Network (ANN) for wireless and nondestructive prediction of soil moisture level. The former system comprising of Near Infrared (NIR) emitters of wavelengths 1200 nm and 1450 nm, and a photodetector mounted on a mobile platform for remote and automated soil moisture measurement in loams and peats holding different amount of water. There were 63 and 90 sets of data from loams and peats, respectively, used in the development of the dual-stage multiclass ANN model, wherein measurement of light attenuation (from nondestructive system) was correlated with percent soil moisture (from destructive gold standard approach). Since there is a considerable overlap in the value of the measurables (for both soil types), this work employed ANN model for each of the considered soil. The result revealed a relatively good performance in the training of the NN with regression, R of 0.8817 and 0.8881, and satisfactory error performance of 0.7898 and 1.172, for loams and peats, respectively. The testing of the system on 50 new samples of loam and peat showed a considerably high mean accuracy of 92 % for loams while 82 % was observed for peats. This study attributes the poorer performance of the system on peats to the analog to digital conversion resolution of HL-69 sensor (measurement of percent soil moisture), and structure and properties of the corresponding soil. This work concluded that the developed technology may be feasible for use in the future design and improvement of agricultural soil management.

ABSTRAK

Tanah adalah salah satu sumber penting yang terdiri daripada mineral atau bahan organik yang tidak disatukan di permukaan bumi; ia memainkan peranan penting dalam pertumbuhan tanaman tanah. Pengujian tanah adalah usaha untuk menilai kesuburan tanah dan tahap kelembapan; maklumat ini berguna untuk menilai kesuburan tanah dan kelangsungan hidup tanaman. Penyelidikan ini menerangkan penggunaan sistem optik yang digabungkan dengan Rangkaian Neural Buatan (RNB) untuk ramalan tahap kelembapan tanah tanpa wayar. Sistem ini terdiri daripada pemancar Inframerah Dekat (ID) dengan panjang gelombang 1200 nm dan 1450 nm, dan fotodetektor yang dipasangkan pada kereta yang mudah alih untuk pengukuran kelembapan tanah dari jauh secara automatik di tanah loam dan tanah gambut yang mempunyai ciri kelembapan air yang berbeza. Terdapat 63 dan 90 set data daripada tanah loam dan gambut akan digunakan dalam pengembangan model RNB multiclass dua peringkat, pengukuran pelemahan cahaya (dari sistem optik) akan berkorelasi dengan peratus kelembapan tanah (dari sistem destruktif). Oleh sebab terdapat banyak pertindihan nilai yang dapat diukur (untuk kedua-dua jenis tanah), karya ini menggunakan model RNB untuk jenis tanah yang dipertimbangkan. Hasilnya menunjukkan prestasi yang baik dengan regresi, *R* dari 0.8817 dan 0.8881, dan prestasi kesalahan yang memuaskan iaitu 0.7898 dan 1.172, untuk tanah loam dan gambut. Ujian lapangan sistem pada 50 sampel baru untuk tanah loam dan gambut menunjukkan ketepatan min yang cukup tinggi 92 % untuk loam sementara 82 % diperhatikan untuk gambut. Kajian ini menunjukkan resolusi penukaran analog ke digital sensor HL-69 (pengukuran peratus kelembapan tanah), dan struktur dan sifat tanah yang sepadan.. Sistem ini menyimpulkan bahawa teknologi yang diperkembangkan adalah layak untuk digunakan pada masa depan untuk peningkatan pengurusan tanah pertanian.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

A	-	Light Attenuation
AI	-	Artificial Intelligent
ANFIS	-	Adaptive Neuro-Fuzzy Inference System
ANN	-	Artificial Neural Network
APK	-	Android Package Kit
CRP	-	Cosmic Ray Probe
d	-	Dark reference
DSMC	-	Dual-stage multiclass
ε	-	Dielectric value
EM	-	Electromagnetic
FCM	-	Fuzzy C means
FDR	-	Frequency-domain reflectometry
GM	-	Gravimetric method
GPR	-	Ground Penetrating Radar
InGaAs	-	Indium gallium arsenide
IEM	-	Integral Equation Model
IoT	-	Internet of Things
l	-	Correlation length
LED	-	Light Emitting Diode
LM	-	Levenberg-Marquardt
MSE	-	Mean Square Error
n_p	-	Number of electrons
NIR	-	Near-infrared
NKEA	-	National Key Economic Areas
NN	-	Neural Network
n_i	-	Number of incident photons

Ø	-	Percent soil moisture
ρ	-	Correlation coefficient
ρ	-	Quantum efficiency
R	-	Regression
r^2	-	Coefficient of determination
RBF	-	Radial Basis Function
RMSE	-	Root Mean Square Error
s	-	Roughness
SLR	-	Single Linear Regression
SPSS	-	Statistical Package for the Social Sciences
SD	-	Standard deviation
SVR	-	Support Vector Regression
TDR	-	Time – domain reflectometry
Ts	-	Propagation time
VWC	-	Volumetric Water Content
w	-	White reference
WCM	-	Water Cloud Model
x	-	Measurement of the soil
z	-	output of the soil moisture sensor

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter is structured as follows: In section 1.2, a brief background and explanation of the topic is included. The problems that inspired the current research work are explained in section 1.3. The objectives of this research are listed in section 1.4. Lastly, the scopes of this work are included in section 1.5.

1.2 Introduction

Soils are one of the essential resources consisting of unconsolidated mineral or organic material on the surface of the earth. This organic matter plays an important role in the growth of land plants. The process of additions, losses, transfers and transformations of energy of soil organic matter provides the ability of the soil to support rooted plants in a natural environment [1]. The different layers of soil include topsoil, eluviated horizon, subsoil, parent material, and bedrock as shown in Figure 1.1. Water may exist in all these layers of soil depending on its percolation rate; this main constituent of earth's hydrosphere is held within the soil pores and it is the major component for plant growth. The colloidal properties and aggregation qualities are the forces responsible for retaining of water in the soil [2]. There are different types of soils including sand, loam, clay, silt, peat and chalk. Among them loam is optimum for plant growth, whilst both silt and peat have high water retention capacity [3]–[5]. The example of plants favourable for growth in loam includes onions, tomatoes and carrots whereas pineapples, potatoes and brassicas are for peat [6], [7].

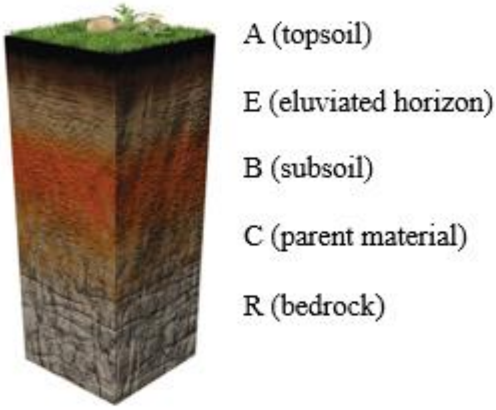

Figure 1.1: The different layers of soil (Image courtesy of the Soil Science Society of America)

Soil testing is an effort to assess soil constituents and moisture level; this information is useful to evaluate soil fertility and plant survival. This would help to determine the amount of additional water level needed for the plantations. Likewise information of soil moisture level is crucial in building and construction engineering; High moisture content would affect land quality, which may cause damage or collapse of the building and infrastructure [8]. The reason behind this issue is due to the strength or compaction of soil. When the soil is in saturated condition, the compaction force between the soil is minimum, hence it is unable to provide support [9]. Therefore, this may present a hazard to the public until appropriate measures are put into place. Meanwhile the interaction forces between soil particles provides strong compaction force when the soil is moist [10].

While the optimum percent soil moisture for most of the plantation crops such corn, wheat and cabbage may range between 15 % and 23 % [11], high moisture content may also result in environmental danger to plants. In the latter case, wilting of plants may ensue if the moisture content exceeds more than 50 % [12]. Water is a moving medium, which helps to deliver nutrients for the plants, and low water content would affect plants growth and theirs yields due to the lack of nutrients uptake. This is in addition to the environmental temperature, which would also have an impact on microbial activities and nutrients uptake. This shift in biological processes during the growing season influences many other relationships such as enzymatic activities and changing in soil chemicals concentrations that are essential for crop performance [13], [14]. The destructive conventional devices for measurement of soil moisture include Time-domain reflectometry (TDR), Frequency-domain reflectometry (FDR), gypsum block and cosmic-ray probe, while nondestructive methods are such as near-infrared (NIR) technique and ground-penetrating radar [15], [16]. In Malaysia, the demand for water increases with rising population and living standard for food production (e.g. agriculture), energy production and domestic purposes (e.g. sanitation) [17]. Therefore, a system is needed to manage the water resources efficiency and effectively [18].

Technology advancement is important in agriculture to increase yields productivity and quality, and for food security [19]. The recent efforts include incorporation of National Key Economic Areas (NKEA) into the Eleventh Malaysia Plan (11MP) [20], which focus is on introducing modern farming techniques and creating market access. Recent progress in Malaysia's agricultural sectors is the increased use of emerging innovative technology, such as database and big data, to initiate smart agriculture. Farmers can remotely manage and control their irrigation equipment. It can also help to monitor soil moisture, crop growth and the level of livestock feed without the need of their presence. This technology revolutionises farming activities and it may be the key to developing sustainable agriculture [19], [21].

1.3 Problem statement

Soil moisture level is affecting productivity and yields of crops and soil fertility. Nowadays, water management is a hot topic especially in agriculture due to the limited water resources that have severely affected several parts of the world such as India [22] and Malaysia [23]. The current state of the arts in the monitoring of soil moisture level includes destructive and nondestructive approaches. Destructive method, also known as a direct approach, requires availability of a sizeable representative terrain from large numbers of soil sample, which samples would be evaluated in a laboratory. These methods include gypsum block and cosmic ray probe, which operation is by the use of a probe for a single point measurement. In addition, these approaches are not suitable for real time application because gypsum block has slow response in the measurement of soil water content changes while cosmic ray probe requires a long set-up time [24], [25]. In addition, the probe used in these detection systems would damage soil structure and may affect quality of the yields. Meanwhile the use of other conventional destructive techniques such as time and frequency domain reflectometry required extensive analysis, and their implementation is limited by the complexity and cost of their operation [24]. Noncontact techniques such as remote sensing is available as an alternative to estimate soil moisture level, but this system involves complicated calculation and the readings can be easily influenced by atmospheric condition [26], [27]. Radiation methods such as neutron scattering and gamma-ray are gaining popularity for their ability to provide accurate measurement of soil moisture result. However, these devices are expensive, they require labor intensive processes (manual application) and high power consumption. In addition neutron probe involves the use of radioactive sources, which would present health and environment hazards if the probe was improperly used [28], [29]. Near Infrared (NIR) spectroscopy is a preferable option to measure the soil moisture but this technology is a bulky system and required 15-30 minutes for soil moisture analysis [30], [31]. The other continuous problem in agricultural production is aging workforce and shortage of worker [32], which would severely affect the productivity. Furthermore, large agricultural area required a large quantity of equipment for sustainability of the farming activities which causes the increase of power consumption, labour costs and water usage [33]. With the wireless technology, farmers are able to directly access the real time information of the soil moisture condition and predict plants growth [34]. Therefore, a low cost and nondestructive system for mobile, safe and rapid measurement of soil moisture level is of utmost needed. It was reported in [32] that majority (i.e. 60.7 %) of farmers are of limited budget, and a low cost system would be beneficial for these farming community and to improve water management in agriculture.

1.4 Objectives

The objectives of this project are:

1) To design and develop a mobile wireless system for nondestructive measurement of soil moisture level
2) To develop a predictive model for soil (loam and peat) moisture level measurement using machine learning technique
3) To evaluate the performance of the developed technology in the prediction of soil moisture level

1.5 Scopes

1) To develop a noncontact and mobile system to predict soil moisture using measurement from optical approach involving light wavelength 1200 nm and 1450 nm. While wavelength 1200 nm is used for reference, the latter is one of the water absorption wavelength peaks. This system is able to move to targeted area for data collection.
2) The near real time prediction system has been designed using neural network in MATLAB.
3) The accuracy of the prediction system is tested on different types of soils namely loam and peat of different volume of water by comparison with ground truth values. Experiment is conducted in laboratory settings.

1.6 Outline of thesis

The organization of this thesis is as below:

Chapter 1 presented the state of art of the soil moisture measurement approaches. The main problems of previous methodologies are discussed and the scopes of this study are proposed.

Chapter 2 reviewed the existing systems and previous works related to the study. Comparison of machine learning techniques has also been discussed.

Chapter 3 described the methodology of this research from the system construction to the results prediction.

Chapter 4 presented results obtained from the system and their analysis.

Chapter 5 discussed the conclusion and recommendation of future directions of this project to further enhance the performance of this system.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter reviews the previous works in this area, which is necessary to establish the general significance of this study. It covers different methods used in the prediction of soil moisture content. This chapter begins with a brief discussion on conventional destructive soil moisture sensing devices and their characteristics in section 2.2. The description and use of nondestructive technique is presented in section 2.3. Previous research works using machine learning in agricultural study are discussed in section 2.4. Last section summarized the comparison of machine learning techniques for soil moisture monitoring.

2.2 Destructive soil moisture sensing devices

The following subsections discussed destructive devices that are available in the market.

2.2.1 Time-Domain Reflectometry (TDR)

TDR is an electronic instrument used to determine the characteristics of electrical lines by observing reflected waveforms. It measures reflections with a conductor. This device has been used for several decades to provide soil moisture content by inserting two probes into the investigated soil as showed in Figure 2.1. This technology measures soil water content based on the travel time of a high-frequency electromagnetic pulse between a pair of rods embedded in the soil. The latter is then used to calculate the permittivity of the material, which can be converted into the required water content level [35]. This system is able to provide accurate result at the price of high cost. To overcome this, Bhushan *et al.* [36] introduced a low-cost TDR system using a microcontroller (AT89S52) and a TDR sensor (PIC 16F1516-I/SO) to detect moisture content of soil sample. The TDR sensor probes were inserted into sample to determine the propagation time (Ts) required by electromagnetic (EM) wave to transmit and reflect back through the soil sample. The result of percent soil moisture measurement was based on reference by Gravimetric method (GM). TDR provided result in digital form and this wireless system is able provide volumetric measurement of water content within 1.2 inches radius around waveguide. The study revealed that mean ± standard deviation (SD) of percentage error and system accuracy was reported as 1.97 ± 0.64 % and 98.02 ± 0.64 %, respectively. In another related study, Abdullah *et al*. [37] determined soil moisture content using TDR that involved the use of two parallel probes to measure the resistance of soil media with pre-determined volumetric water content. This system is shown to produce relatively good accuracy of less than 30 % in its measurement, which metric was shown to compromise as the water content increases. Therefore, it is recommended that an enhanced numerical tool with a correction factor to be determined to improve its accuracy in the future. The limitation of this technology is the requirement of calibration for each soil sample and its single point, localized measurement [38]. It must be mentioned that TDR sensors, which measurement depth is limited by the probe length, must establish good contact with the soil to avoid the air gaps within the investigation medium to prevent erroneous measurements. In addition, TDR is not suitably used in high saline soil due to its high electrical conductivity (EC) that prevents voltage pulses from reflected between the probe [39].

Figure 2.1: Time Domain Reflectometry (TDR) on soil sample

2.2.2 Frequency Domain Reflectometry (FDR)

FDR exhibits similar characteristics as TDR in the measurement of soil moisture content. This instrument consists of a capacitor and makes use of radio frequency to determine the value of the required parameter. This method uses an oscillator to propagate an electromagnetic signal through a metal tube or other waveguide. The difference between the output wave and the returning wave frequency is measured to determine the soil moisture level. Lukanu *et al.* [40] reported the use of FDR technique in approximating the soil moisture level by using factory-supplied parameters for a better performance, which coefficient of determination (r^2) is given by 0.92. This parameter r^2 is normally taken to be analogous to regression (R) and correlation coefficient (ρ) [41]. An R value closes to value one indicated the presence of linear relationship between the variables [42] while lower Mean Square Error (MSE) values indicate better fit in the obtained data with the predicted values [43], [44]. Furthermore, regression method for prediction can help work to gain a far greater understanding of the variables that can impact its success in the coming weeks, months and years into the future. The advantage of regression analysis is that it can allow user to essentially make better decisions for predict volume of water. In another work, Minet *et al*. [45] demonstrated a generalized FDR technique to determine soil electrical characteristics based on electromagnetic model decoupling. The FDR model used in the work was to provide frequency-dependent reflection and transmission transfer functions for prediction of volumetric water content; this technique was reported to offer a faster response as compared to TDR. Additionally FDR technique uses selective frequencies, consequently its measurement accuracy is better than TDR [46]. Although FDR is able to provide reliable result for measurement of soil moisture content, it required specific calibration which probe need to be buried into soil, and the system is costly [47].

2.2.3 Gypsum Block

Gypsum block shown in Figure 2.2 is one of the most economic soil moisture monitoring systems. Soil moisture meter combined with gypsum blocks was proposed for the measurement [48]–[50]. The soil moisture is determined by measuring the resistance between two electrodes inside the block, which increases when the soil dries out, and vice versa. This technique also is not frost and salt resistant. However, this block of system needs to be buried inside the soil at certain depth level for effective measurement and the lifespan of blocks is between 3 to 5 years. The readings may be taken manually using a hand-held reader with retrieval device such as a portable meter, which process can be laborious. Dwevedi *et al*. [51] developed a gypsum block to measure soil moisture level and store data for irrigation application. Meanwhile Keyhani *et al.* [52] presented the use of a mini gypsum block for application on limited soil depth. The resolution of data acquisition system was, however, a limiting factor in calibrating this gypsum block in lower soil suctions, which is corresponding to lower gravimetric water contents, due to deep cracks formed during the drying process of the top soil layer down to the mini gypsum block sensor.

REFERENCES

[1] M. Hanin, C. Ebel, M. Ngom, and L. Laplaze, "New Insights on Plant Salt Tolerance Mechanisms and Their Potential Use for Breeding," vol. 7, no. November, pp. 1–17, 2016.

[2] J. M. Oades and A. G. Waters, "Aggregate hierarchy in soils," *Aust. J. Soil Res.*, vol. 29, no. 6, pp. 815–825, 1991.

[3] A. Abdulazeez, "Effects of Soil Texture on Vegetative and Root Growth of Senna obtusifolia seedlings indigenous to Bichi , Sudan savannah of Northern Nigeria , in Green House Conditions," *IOSR J. Agric. Vegerinary Sci.*, vol. 10, no. 4, pp. 70–74, 2017.

[4] C. V. Patricia, M. M. Elizabeth, A. Campos, I. Espejel, and J. Luis, "Mangrove and Freshwater Wetland Conservation Through Carbon Offsets : A Cost-Bene fi t Analysis for Establishing Environmental Policies," *Environ. Manage.*, pp. 274–290, 2017.

[5] S. Tahir and P. Marschner, "Clay amendment to sandy soil — effect of clay concentration and ped size on nutrient dynamics after residue addition," 2016.

[6] Lynn Cochran, "Flowers and Vegetables for Sandy Loam Soil," *SF Gate*, 2018. [Online]. Available: https://homeguides.sfgate.com/flowers-vegetables-sandy-loam-soil-55505.html.

[7] Ruth Barto, "Know Your Garden Soil: How to Make the Most of Your Soil Type," *Eartheasy*, 2013.

[8] K. K. Toll, D.G. and Abedin, Z. and Buma, J. and Cui, Y. and Osman, A. S. and Phoon, "The impact of changes in the water table and soil moisture on structural stability of buildings and foundation systems," vol. 44, no. April, 2016.

[9] M. Jourgholami, "Effects of soil compaction on growth variables in Cappadocian maple (Acer cappadocicum) seedlings," *J. For. Res.*, vol. 29, no. 3, pp. 601–610, 2018.

[10] D. C. W. W. L. Schroeder, S. E. Dickenson, *Soils in Construction: Fifth Edition*, Fifth Edit. 2017.

[11] B. N. and S. B. R. Singh, "Growth And Water Requirement of Crop Plants in Relation to soil moisture," pp. 376–402, 1936.

[12] Larry Pitts, "Monitoring Soil Moisture for Optimal Crop Growth," *Observant*, 2016. [Online]. Available: https://observant.zendesk.com/hc/en-us/articles/208067926-Monitoring-Soil-Moisture-for-Optimal-Crop-Growth.

[13] S. Chatterjee, "Hybrid Regression Model for Soil Moisture Quantity Prediction," *2019 Int. Conf. Opto-Electronics Appl. Opt.*, pp. 1–5, 2019.

[14] Mahdi Al-Kaisi, "How Drought Affects Soil Health," *Iowa State University of Science and Technology*, 2017. [Online]. Available: https://crops.extension.iastate.edu/cropnews/2017/08/how-drought-affects-soil-health.

[15] P. Zhou, Y. Zhang, W. Yang, M. Li, Z. Liu, and X. Liu, "Development and performance test of an in-situ soil total nitrogen-soil moisture detector based on near-infrared spectroscopy," *Comput. Electron. Agric.*, vol. 160, no. March, pp. 51–58, 2019.

[16] X. Liu, J. Chen, X. Cui, Q. Liu, X. Cao, and X. Chen, "Measurement of soil water content using ground- penetrating radar : a review of current methods," *Int. J. Digit. Earth*, vol. 0, no. 0, pp. 1–24, 2017.

[17] S. Mohammad, F. Islam, and Z. Karim, "World ' s Demand for Food and Water : The Consequences of Climate Change," *IntechOpen*, pp. 1–27, 2019.

[18] D. P. Loucks, E. Van Beek, W. Resource, and S. Planning, *Water Resources Planning and Management: An Overview*. Springer, Cham, 2017.

[19] Dr. Shahino Mah Abdullah, "Ecological agriculture: Farming the smart way," *New Straits Times*, 2017.

[20] R. A. Dardak, "New Strategies for Greater Growth and Development of the Agriculture Sector in Malaysia," pp. 1–5, 2020.

[21] Sharala Axryd & Chari TVT, "A Digital Solution Towards Data-Drive Agriculture in Malaysia," *Digital New Asia*, 2019. [Online]. Available: https://www.digitalnewsasia.com/insights/digital-solution-towards-data-driven-agriculture-malaysia.

[22] C. Singh, "The implications of rural perceptions of water scarcity on differential adaptation behaviour in Rajasthan , India," pp. 2417–2432, 2018.

[23] K. E. Lee, M. Mokhtar, M. M. Hanafiah, A. A. Halim, and J. Badusah, "Rainwater harvesting as an alternative water resource in Malaysia: potential,

policies and development," *J. Clean. Prod.*, 2016.

[24] A. Bianchi, D. Masseroni, M. Thalheimer, F. Agriculture, F. Laimburg, and L. Medici, "Field irrigation management through soil water potential measurements : a review," no. October, 2017.

[25] I. T. Series, "Soil Moisture Mapping with a Portable Cosmic Ray Neutron Sensor," *Conf. Statut. IAEA*, 2018.

[26] M. Sadeghi, S. B. Jones, and W. D. Philpot, "A linear physically-based model for remote sensing of soil moisture using short wave infrared bands," *Remote Sens. Environ.*, vol. 164, pp. 66–76, 2015.

[27] V. Moosavi, A. Talebi, M. H. Mokhtari, and M. R. Hadian, "Estimation of spatially enhanced soil moisture combining remote sensing and artificial intelligence approaches," *Int. J. Remote Sens.*, vol. 37, no. 23, pp. 5605–5631, 2016.

[28] A. Robock and N. Brunswick, "Soil Moisture," vol. 3, pp. 232–239, 2015.

[29] C. M. Enrique, C. Vicente, C. S. Eduardo, and D. Articulo, "Soil water deficiency and biological Nitrogen fixation in common bean crop," pp. 94–106, 2017.

[30] B. K. Waruru, K. D. Shepherd, G. M. Ndegwa, A. Sila, and P. T. Kamoni, "Application of mid-infrared spectroscopy for rapid characterization of key soil properties for engineering land use," *Soils Found.*, vol. 55, no. 5, pp. 1181–1195, 2015.

[31] J. M. Soriano-disla, L. J. Janik, R. A. V. Rossel, L. M. Macdonald, and M. J. Mclaughlin, "The Performance of Visible , Near- , and Mid-Infrared Reflectance Spectroscopy for Prediction of Soil Physical , Chemical , and Biological Properties," *Appl. Spectrocopy Rev.*, vol. 49, no. August 2013, pp. 37–41, 2014.

[32] S. Shekhar, J. Colletti, C. Krintz, and F. Muñoz-arriola, "Intelligent Infrastructure for Smart Agriculture : An Integrated Food , Energy and Water System," no. March 2014, pp. 1–8, 2017.

[33] B. Kempegowda, "An Intelligent Water Management in Farming through the IoT," *Res. Gate*, no. October, 2019.

[34] H. M. Jawad, R. Nordin, and S. K. Gharghan, "Energy-Efficient Wireless Sensor Networks for Precision Agriculture : A Review," *Sensors*, 2017.

[35] J. Liu, P. Shrestha, L. R. Skabelund, T. Todd, A. Decker, and M. B. Kirkham, "Growth of prairie plants and sedums in different substrates on an experimental green roof in Mid-Continental USA," *Sci. Total Environ.*, vol. 697, p. 134089, 2019.

[36] B. N. Patil, P. H. Zope, and K. S. Patil, "Development of Low Cost TDR System for Soil Moisture Measurement," *Int. J. Adv. Res. Educ. Technol.*, vol. 2, no. 3, pp. 17–26, 2015.

[37] R. R. and N. S. M. N. H. H. Abdullah, N. W. Kuan, A. Ibrahim, B. N. Ismail, M. R. A. Majid, "Determination of soil water content using time domain reflectometer (TDR) for clayey soil Determination of Soil Water Content Using Time Domain Reflectometer (TDR) for Clayey Soil," vol. 020016, no. October 2018, 2020.

[38] G. Curioni *et al.*, "Time domain reflectometry (TDR) potential for soil condition monitoring of geotechnical assets," *NRC Res. Press*, vol. 955, no. August 2018, pp. 942–955, 2019.

[39] O. Saha, M. Boulfiza, and L. D. Wegner, "Tracking the hydration of antifreeze treated cement paste at subfreezing temperatures using the TDR technique," *Constr. Build. Mater.*, vol. 262, p. 119915, 2020.

[40] G. Lukanu and M. J. Savage, "Calibration of a frequency-domain reflectometer for determining soil-water content in a clay loam soil," *Water SA*, vol. 32, no. 1, pp. 37–42, 2006.

[41] C. Cheng and G. Garg, "Coefficient of determination for multiple measurement error models," *J. Multivar. Anal.*, vol. 126, pp. 137–152, 2014.

[42] D. M. A. Zaid, *Correlation and Regression Analysis*. 2015.

[43] E. Heidaryan, "A note on model selection based on the percentage of accuracy-precision," no. c, 2018.

[44] Z. Zhang, "Model building strategy for logistic regression : purposeful selection," *AME Publ.*, vol. 4, no. 6, pp. 4–10, 2016.

[45] J. Minet, S. Lambot, G. Delaide, J. A. Huisman, H. Vereecken, and M. Vanclooster, "A Generalized Frequency Domain Reflectometry Modeling Technique for Soil Electrical Properties Determination," *Vadose Zo. J.*, vol. 9, no. 4, p. 1063, 2010.

[46] A. Brandelik and C. Hiibner, "Soil Moisture Determination - Accurate , Large and Deep," vol. 21, no. 3, pp. 157–160, 1997.

[47] J. D. Gonz, R. Torres-s, P. J. Blaya-ros, A. B. Toledo-moreo, M. Jim, and F. Soto-valles, "Design and Calibration of a Low-Cost SDI-12 Soil Moisture Sensor," 2019.

[48] Y. Hoseini and M. Albaji, "Calibration of Gypsum Blocks for Measuring Saline Soils Moisture," *Commun. Soil Sci. Plant Anal.*, vol. 47, no. 22, pp. 2528–2537, 2016.

[49] E. Stenitzer, "Monitoring soil moisture regimes of field crops with gypsum blocks," *Theor. Appl. Climatol.*, vol. 48, no. 2–3, pp. 159–165, 1993.

[50] J. Veeranna, N. Patel, A. K. Mishra, C. Varghese, and N. Sandeep, "Performance evaluation of gypsum block wireless sensor network system for real time irrigation scheduling," *Cogent Eng.*, vol. 3, no. 1, pp. 1–16, 2016.

[51] A. Dwevedi, P. Kumar, P. Kumar, Y. Kumar, Y. K. Sharma, and A. M. Kayastha, *Soil sensors: detailed insight into research updates, significance, and future prospects*. Elsevier Inc., 2017.

[52] A. Keyhani, "Development of mini-gypsum blocks for soil moisture measurement and their calibration to compensate for temperature," *J. Agric. Sci. Technol.*, vol. 3, pp. 141–145, 2010.

[53] M. Schrön, "Cosmic-Ray Neutron Sensing and its Applications to Soil and Land Surface Hydrology," *Institutional Repos. Univ. Potsdam*, 2017.

[54] M. Schrön *et al.*, "Improving calibration and validation of cosmic-ray neutron sensors in the light of spatial sensitivity," pp. 5009–5030, 2017.

[55] I. Heidbuchel, A. Guntner, and T. Blume, "Use of cosmic-ray neutron sensors for soil moisture monitoring in forests," *Hydrol. Earth Syst. Sci.*, vol. 20, no. 3, pp. 1269–1288, 2016.

[56] T. Vather, C. Everson, M. Mengistu, and T. Franz, "Cosmic ray neutrons provide an innovative technique for estimating intermediate scale soil moisture," *S. Afr. J. Sci.*, vol. 114, no. 7–8, pp. 79–87, 2018.

[57] R. Dutta, A. Terhorst, A. Hawdon, and B. Cotching, "Bulk soil moisture estimation using CosmOz cosmic ray sensor and ANFIS," *Proc. IEEE Sensors*, 2012.

[58] L. Stevanato *et al.*, "A Novel Cosmic-Ray Neutron Sensor for Soil Moisture Estimation over Large Areas," *Agriculture*, 2019.

[59] H. V. R. Baatz, H. R. Bogena, H.-J. Hendricks Franssen, J. A. Huisman, C. Montzka, "An empirical vegetation correction for soil water content

quantification using cosmic ray probes," *Water Resour. Res.*, pp. 2030–2046, 2015.

[60] Z. Yin *et al.*, "Reflection Model for Soil Moisture Measurement Using Near-infrared Reflection Sensor," no. Ifeesm, pp. 854–860, 2015.

[61] X. Liang, X. Li, and T. Lei, "A new NIR technique for rapid determination of soil moisture content," *2012 Int. Conf. Syst. Informatics, ICSAI 2012*, no. Icsai, pp. 16–20, 2012.

[62] E. Tamburini, F. Vincenzi, S. Costa, P. Mantovi, P. Pedrini, and G. Castaldelli, "Effects of Moisture and Particle Size on Quantitative Determination of Total Organic Carbon (TOC) in Soils Using Near-Infrared Spectroscopy," pp. 1–15, 2017.

[63] N. Izzati, A. Karim, S. A. Kamaruddin, and Z. M. Hasan, Rozaimi Che, Amin, "Application of Ground Penetrating Radar on Soil Water Content Estimation : an Overview," *Int. Grad. Conf. Eng. Sci. Humanit.*, no. 2016, pp. 1–8, 2016.

[64] M. C. Vuran, A. Salam, R. Wong, and S. Irmak, "Internet of Underground Things in Precision Agriculture: Architecture and Technology Aspects Mehmet," *Ad Hoc Networks*, 2018.

[65] R. Mardeni, "Soil Moisture Estimation via Radio Wave Reflection Method using Ground Penetrating Radar," no. 2, pp. 533–535, 2015.

[66] Y. C. W., M. R., and A. N. N., "Microwave Surface Reflection Method for Soil Moisture Determination Using frequency of 1.7-2.6 GHz," *Mod. Appl. Sci.*, vol. 9, no. 13, p. 71, 2015.

[67] G. C. Topp, "Electromagnetic Determination of Soil Water Content:," *Water Resour. Res.*, vol. 16, no. 3, pp. 574–582, 1980.

[68] I. A. Lunt, S. S. Hubbard, and Y. Rubin, "Soil moisture content estimation using ground-penetrating radar reflection data," *J. Hydrol.*, vol. 307, no. 1–4, pp. 254–269, 2005.

[69] S. K. and J.-S. L. Won-Taek Hong, Young-Seok Jung, "Estimation of Soil-Water Characteristic Curves in Multiple-Cycles Using Membrane and TDR System," 2016.

[70] M. Quinta-ferreira, "Ground Penetration Radar in Geotechnics . Advantages and Limitations," 2019.

[71] E. T. Engman, "Progress in Microwave Remote Sensing of Soil Moisture," vol. 8992, no. April, 2016.

[72] K. C. Kornelsen and P. Coulibaly, "Advances in soil moisture retrieval from synthetic aperture radar and hydrological applications," *J. Hydrol.*, vol. 476, pp. 460–489, 2013.

[73] X. Chen, S. Chen, R. Zhong, Y. Su, J. Liao, and D. Li, "A semi-empirical inversion model for assessing surface soil moisture using AMSR-E brightness temperatures," *J. Hydrol.*, vol. 456–457, pp. 1–11, 2012.

[74] D. Singh and A. Kathpalia, "An Efficient Modeling With ga Apporach to Retrieve Soil Texture Moisture And Roughness From ERS-2 Data," pp. 121–136, 2007.

[75] T. Jayanthi, B. S. Navya, and K. Vanitha, "Microwave Moisture Measurement Technique In Industrial Application," vol. 1, 2015.

[76] K. Das and P. K. Paul, "Present status of soil moisture estimation by microwave remote sensing," pp. 1–21, 2015.

[77] S. Muhammad, Z. Younis, and J. Iqbal, "Estimation of soil moisture using multispectral and FTIR techniques," *Egypt. J. Remote Sens. Sp. Sci.*, vol. 18, no. 2, pp. 151–161, 2015.

[78] A. A. M. Ichwana, Zulkifli Nasution, "The Application Of Fourier Transform Infrared Photoacoustics Spectroscopy (FTIR- PAS) For Rapid Soil Quality Evaluation," *J. Rona Tek. Pertan.*, vol. 10, no. April, pp. 1–8, 2017.

[79] A. J. Margenot and F. J. Calderón, "Limitations and Potential of Spectral Subtractions in Fourier-Transform Infrared Spectroscopy of Soil Samples," 2016.

[80] D. Walsh *et al.*, "Long-term monitoring of soil moisture content using portable NMR instruments," *J. Environ. Eng. Geophys.*, p. 2, 2018.

[81] W. L. and Q. R. Rugao Gao, Keping Zhou, "Correlation between the Pore Structure and Water Retention of Cemented Paste Backfill Using," *Minerals*, 2020.

[82] V. Der Fakult, "A Low-Field NMR Tool for Soil Moisture," 2011.

[83] F. Jonard *et al.*, *Ground-Based Soil Moisture Determination*. Springer Berlin Heidelberg, 2018.

[84] V. S. Nayak, M. S. Khan, B. K. Shukla, and P. R. Chaturvedi, "Artificial intelligence in clinical research," *Int. J. Clin. Trials*, vol. 3, no. 4, p. 187, 2016.

[85] I. R. and A. V.-Q. J. A. García-Esteban, B. Curto, V. Moreno, I. González-Martín, "A digitalization strategy for quality control in food industry based on

Artificial Intelligence techniques," *IEEE 16th Int. Conf. Ind. Informatics*, pp. 221–226, 2018.

[86] P. G. Tripathi, "Home Automation System using Artificial Intelligence," *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. V, no. VIII, pp. 219–224, 2017.

[87] M. Waleed, T. Um, T. Kamal, A. Khan, and A. Iqbal, "Determining the Precise Work Area of Agriculture Machinery Using Internet of Things and Artificial Intelligence," 2020.

[88] V. K. Dadhwal, S. Applications, and C. Isro, "Crop Growth and Productivity Monitoring and Simulation Using Remote Sensing and GIS," *Satell. Remote Sens. GIS Appl. Agric. Meteorol.*, pp. 263–289, 2003.

[89] I. A. Lakhiar, G. Jianmin, T. N. Syed, F. A. Chandio, N. A. Buttar, and W. A. Qureshi, "Review Article Monitoring and Control Systems in Agriculture Using Intelligent Sensor Techniques : A Review of the Aeroponic System," vol. 2018, 2018.

[90] A. Y. Prosekov and S. A. Ivanova, "Food security : The challenge of the present," *Elsevier*, vol. 91, no. August 2017, pp. 73–77, 2018.

[91] H. Liauw and S. S. Chai, "Comparison of Data Driven Models (DDM) for Soil Moisture Retrieval using Microwave Remote Sensing Data," *2015 9th Int. confrence IT Asia*, no. Ddm, pp. 1–5, 2015.

[92] N. J. and A. F. Idrees Zaman, "Artificial Neural Network based Soil VWC and Field Capacity Estimation Using Low Cost Sensors," 2018.

[93] S. S. Zanetti, R. A. Cecílio, V. H. Silva, and E. G. Alves, "General calibration of TDR to assess the moisture of tropical soils using artificial neural networks," *J. Hydrol.*, vol. 530, pp. 657–666, 2015.

[94] H. Liu and L. Wang, "International Journal of Industrial Ergonomics Gesture recognition for human-robot collaboration : A review," *Int. J. Ind. Ergon.*, pp. 1–13, 2017.

[95] J. Stamenkovic, P. Ferrazzoli, L. Guerriero, D. Tuia, J. Thiran, and M. Borgeaud, "Crop Backscatter Modeling and Soil Moisture Estimation with Support Vector Regression Ecole Polytechnique Fédérale de Lausanne (EPFL), Laboratory of Geographic Information Systems," pp. 3228–3231, 2014.

[96] J. Stamenkovic, D. Tuia, F. De Morsier, M. Borgeaud, and J. P. Thiran, "Estimation of soil moisture from airborne hyperspectral imagery with support vector regression," *Work. Hyperspectral Image Signal Process. Evol. Remote*

Sens., vol. 2013–June, pp. 1–4, 2017.

[97] R. Solorza, C. Notarnicola, and H. Karszenbaum, "Retrieval of soil moisture using electromagnetic models and a Bayesian approach in view of the SAOCOM mission: Study on SARAT images in an agricultural site in Argentina," *Int. Geosci. Remote Sens. Symp.*, pp. 739–742, 2013.

[98] X. Wu, J. P. Walker, C. Rüdiger, R. Panciera, and Y. Gao, "Medium-Resolution Soil Moisture Retrieval Using the Bayesian Merging Method," *IEEE Trans. Geosci. Remote Sens.*, vol. 55, no. 11, pp. 6482–6493, 2017.

[99] Q. Yuan, H. Shen, T. Li, Z. Li, S. Li, and Y. Jiang, "Remote Sensing of Environment Deep learning in environmental remote sensing : Achievements and challenges," *Remote Sens. Environ.*, vol. 241, no. January, p. 111716, 2020.

[100] X. Qiao and F. Yang, "The Prediction Method of Soil Moisture Content Based on Multiple Regression and RBF Neural Network," no. 6, pp. 140–143, 2014.

[101] F. Rahimi-Ajdadi, Y. Abbaspour-Gilandeh, K. Mollazade, and R. P. R. Hasanzadeh, "Development of a novel machine vision procedure for rapid and non-contact measurement of soil moisture content," *Meas. J. Int. Meas. Confed.*, vol. 121, pp. 179–189, 2018.

[102] L. Chhay, A. Hossain, R. Rathny, S. Rafiqul, and I. Manik, "Municipal solid waste generation in China : Influencing factor analysis and multi-model forecasting," *J. Mater. Cycles Waste Manag.*, vol. 0, no. 0, p. 0, 2018.

[103] M. Khan and S. Noor, "Performance Analysis of Regression-Machine Learning Algorithms for Prediction of Runoff Time Agrotechnology," *Agrotechnology*, vol. 8, no. 1, pp. 1–12, 2019.

[104] N. O. Hodas and P. Stinis, "Doing the Impossible : Why Neural Networks Can Be Trained at All," vol. 9, no. July, pp. 1–7, 2018.

[105] C. S. Hajjar, C. Hajjar, M. Esta, Y. G. Chamoun, I. De Gestion, and U. S. De Beyrouth, "Machine learning methods for soil moisture prediction in vineyards using digital images," vol. 02004, 2020.

[106] H. Wang and D. Xu, "Parameter Selection Method for Support Vector Regression Based on Adaptive Fusion of the Mixed Kernel Function," vol. 2017, 2017.

[107] J. Bao, Z. Hou, J. Ray, M. Huang, L. Swiler, and H. Ren, "Soil moisture estimation using tomographic ground penetrating radar in a MCMC – Bayesian framework," *Stoch. Environ. Res. Risk Assess.*, vol. 32, no. 8, pp. 2213–2231,

2018.

[108] W. T. A. Id, W. Ji, and M. Id, *Comparing Bayesian and non-Bayesian accounts of human confidence reports*. 2018.

[109] J. G. Egbe *et al.*, "Application of Multilinear Regression Analysis in Modeling of Soil Properties for Geotechnical Civil Engineering Works in Calabar South," vol. 36, no. 4, pp. 1059–1065, 2017.

[110] C. Abelmann, Leon. Badugu, R. Calucci, Lucia. Das, B.B. Eccles, *Encyclopedia of Spectroscopy and Spectrometry*. Elsevier Ltd, 2017.

[111] I. Ali, F. Greifeneder, J. Stamenkovic, M. Neumann, and C. Notarnicola, "Review of Machine Learning Approaches for Biomass and Soil Moisture Retrievals from Remote Sensing Data," *Remote Sens.*, pp. 16398–16421, 2015.

[112] Y. Zhou *et al.*, "Artificial neural network based multivariable optimization of a hybrid system integrated with phase change materials , active cooling and hybrid ventilations," *Energy Convers. Manag.*, vol. 197, no. March, p. 111859, 2019.

[113] S. Physics, I. Unit, and N. Agriculture, "Effect of sensor installation on the accurate measurement," no. November, pp. 817–828, 2017.

[114] S. N. Haubrock, S. Chabrillat, C. Lemmnitz, and H. Kaufmann, "Surface soil moisture quantification models from reflectance data under field conditions," vol. 1161, 2010.

[115] R. K. Kodali and A. Sahu, "An IoT Based Soil Moisture Monitoring on Losant Platform," pp. 764–768, 2016.

[116] J. Rodr, Á. Martin, S. Martin, A. Ruip, and M. Castro, "Autonomous Sensor Network for Rural Agriculture Environments , Low Cost , and Energy Self-Charge," 2020.

[117] M. Hong Xuan Wai, X. Ngu, and A. Huong, "Agricultural Water Management using Artificial Neural Network," *Int. J. Adv. Sci. Technol.*, vol. 29, no. 6, pp. 770–776, 2020.

[118] P. Jariyayothin, K. Jeravong-aram, and N. Ratanachaijaroen, "IoT Backyard : Smart Watering Control System," pp. 2–7, 2018.

[119] P. Soham, Adla. Neeraj Kumar, Rai. Sri Harsha Karumanchi . Shivam, Tripath. Markus, Disse. and Saket, "Laboratory Calibration and Performance Evaluation of Low-Cost Capacitive and Very Low-Cost Resistive Soil Moisture Sensors," vol. 69, 2020.

[120] J. O. Payero, A. M. Nafchi, R. Davis, and A. Khalilian, “An Arduino-Based Wireless Sensor Network for Soil Moisture Monitoring Using Decagon EC-5 Sensors,” *J. Soil Sci.*, pp. 288–300, 2017.

[121] Z. Yin, T. Lei, Q. Yan, Z. Chen, and Y. Dong, “A near-infrared reflectance sensor for soil surface moisture measurement,” *Comput. Electron. Agric.*, vol. 99, pp. 101–107, 2013.

[122] J. A. Gamon, B. S. Z. Malenovský, and E. M. M. U. Rascher, “Assessing Vegetation Function with Imaging Spectroscopy,” *Surv. Geophys.*, vol. 40, no. 3, pp. 489–513, 2019.

[123] M. Kowalczyk, “Influence of reverse bias on the LEDs properties used as photo-detectors in VLC systems,” no. November, 2017.

[124] Bernd J. Pichler and Sibylle I.Ziegler, “Photodetectors,” pp. 255–267, 2004.

[125] A. Huong and X. Ngu, “Noninvasive Diagnosis of Carbon Monoxide Poisoning Using Extended Modified Lambert Beer Model,” no. August 2014, 2017.

[126] A. Hamidisepehr, M. P. Sama, and A. P. Turner, “A Method for Reflectance Index Wavelength Selection from Moisture-Controlled Soil and Crop Residue Samples,” *Am. Soc. Agric. Biol. Eng.*, vol. 60, pp. 1479–1487, 2017.

[127] I. A. Karim, S. A. Kamaruddin, and R. C. Hasan, “The Petrophysical Relationship between the Dielectric Permittivity and Water Content of Peat Soil Moisture Measurements,” *2018 2nd Int. Conf. Smart Sensors Appl.*, pp. 147–151, 2018.

[128] Y. A. Goh, K.J., Mahamooth, T.N., Patrick Ng, H.C., Teo, C.B., and Liew, “Managing Soil Environment and Its Major Impact on Oil Palm Nutrition and Productivity in Malaysia,” *One oil palm*, no. 11, pp. 1–71, 1994.

[129] V. Spalevic, K. Lisichkov, and R. Gulaboski, “Determination of Water Retention Characteristics of Perlite,” no. October, 2018.

[130] Z. Wang, X. Li, H. Shi, W. Li, W. Yang, and Y. Qin, “Estimating the water characteristic curve for soil containing residual plastic film based on an improved pore-size distribution,” *Elsevier*, vol. 370, no. August 2019, p. 114341, 2020.

[131] C. Brischke and F. L. Wegener, “Impact of Water Holding Capacity and Moisture Content of Soil Substrates on the Moisture Content of Wood in Terrestrial Microcosms,” *Res. Gate*, vol. 10, no. 6, 2019.

[132] ISCC, “Clay , Sandy and Peat Soils , and Soil Organic Matter,” 2018.

[133] J. Ball, “Soil and Water Relationships,” pp. 40–42, 2011.

[134] F. Rezanezhad, J. S. Price, W. L. Quinton, B. Lennartz, T. Milojevic, and P. Van Cappellen, “Structure of peat soils and implications for water storage, flow and solute transport : A review update for geochemists,” *Chem. Geol.*, vol. 429, pp. 75–84, 2016.

[135] J. D. Yonggang Yao, Jinsong Tao, Jianhua Zou, Bilun Zhang, Tian Li and L. H. Mingwei Zhu, Sha Wang, Kun Kelvin Fu, Doug Henderson, Emily Hitz, Junbiao Peng, “Light management in plastic–paper hybrid substrate towards high-performance optoelectronics,” *Energy Environ. Sci.*, no. 7, 2016.

[136] K. Bacon, A. Blundell, M. Bourgault, and P. J. Chapman, “Questioning ten common assumptions about peatlands,” *Res. Gate*, no. July, 2017.

[137] T. D. P. Liyanage and D. A. L. Leelamanie, “Influence of organic manure amendments on water repellency , water entry value , and water retention of soil samples from a tropical Ultisol,” *J. Hydrol. Hydromechanics*, vol. 64, no. 2, pp. 160–166, 2016.

[138] K. Chaudhary, “Prediction of Crop Yield Using Machine Learning,” *Int. J. Eng. Appl. Sci. Technol.*, vol. 4, no. 9, pp. 153–156, 2020.

[139] I. P. Senanayake, G. R. Willgoose, G. R. Hancock, and D. Bretreger, “Using an artificial neural network to enhance the spatial resolution of satellite soil moisture products based on soil thermal inertia,” no. December, pp. 1049–1055, 2019.

[140] M. T. Hagan and M. B. Menhaj, “Training Feedforward Networks with the Marquardt Algorithm,” *IEEE Trans. Neural Networks*, vol. 5, no. 6, pp. 2–6, 1994.

[141] A. Huong and X. Ngu, “Neural Network approach for rapid prediction of transcutaneous oxygen saturation,” *2019 IEEE 9th Symp. Comput. Appl. Ind. Electron.*, pp. 239–243, 2019.

[142] H. Qi and F. Huang, “Monitoring Spatio-Temporal Changes of Terrestrial Ecosystem Soil Water Use Efficiency in Northeast China Using Time Series Remote Sensing Data,” *Sensors*, 2019.

[143] J. L. N. Elyas Hayati, Ehsan Abdi, Mohsen Mohseni Saravi and and M. N. Baris Majnounian, Giovanni B. Chirico, Bruce Wilson, “Soil water dynamics under different forest vegetation cover: Implications for hillslope stability,” *J. Br. Soc. Geomorphol.*, vol. 43, no. 10, pp. 2106–2120, 2018.

[144] Z. M. Easton, E. Specialist, B. S. Engineering, and V. Tech, “Soil and Soil Water Relationships,” 2016.

[145] B. Xiao and M. A. Bowker, “Moss-biocrusts strongly decrease soil surface albedo, altering land-surface energy balance in a dryland ecosystem,” *Sci. Total Environ.*, p. 140425, 2020.

[146] J. P. B. J. H. C.-T. ; J. E. Vélez-Sánchez, “Estimating soil properties with mid-infrared spectroscopy,” 2016.

[147] A. Bablet *et al.*, “MARMIT : A multilayer radiative transfer model of soil reflectance to estimate surface soil moisture content in the solar domain (400 – 2500 nm) To cite this version : HAL Id : hal-02118848,” 2019.

[148] M. Wutke, A. Lejzerowicz, W. Jackiewicz-rek, and A. Garbacz, “Influence of variability of water content in different states on electromagnetic waves parameters affecting accuracy of GPR measurements of asphalt and concrete pavements,” vol. 06012, pp. 1–6, 2019.

[149] E. Babaeian, M. Sadeghi, S. B. Jones, C. Montzka, and H. Vereecken, *Ground , Proximal and Satellite Remote Sensing of Soil Moisture*. American Geophysical Union, 2019.

[150] S. D. C. A. Tyas and J. A. Warren, “Effect of Moisture Content on High Strain Rate Compressibility and Particle Breakage in Loose Sand,” *Springer Link*, pp. 1331–1334, 2018.

[151] M. Knadel and S. Katuwal, “Visible-Near-Infrared Spectroscopy Prediction of Soil Characteristics as Affected by Soil-Water Content,” 2018.

[152] C.-W. Chang and J. , David A. Laird, and Charles R. Hurburgh, “Influence of Soil Moisture on Near-Infrared Reflectance,” pp. 244–255, 2005.

[153] D. B. Lobell and G. P. Asner, “Moisture Effects on Soil Reflectance,” pp. 722–727, 2002.

[154] M. Sadeghi, E. Babaeian, M. Tuller, and S. B. Jones, “Particle size effects on soil reflectance explained by an analytical radiative transfer model,” vol. 210, no. September 2017, pp. 375–386, 2018.

[155] B. Stenberg, R. A. V. Rossel, and A. M. Mouazen, “Visible and near infrared spectroscopy in soil science,” vol. 107, no. 10, pp. 1–44, 2010.

[156] J. J. Roberts and D. Cozzolino, “Trends in Analytical Chemistry Wet or dry ? The effect of sample characteristics on the determination of soil properties by near infrared spectroscopy,” *Trends Anal. Chem.*, vol. 83, pp. 25–30, 2016.

[157] D. C. Slaughter, M. G. Pelletier, and S. K. Upadhyaya, “Sensing Soil Moisture Using NIR Spectroscopy,” vol. 17, no. 2, pp. 241–247, 2001.